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Stimulus and Response-Locked P3 Activity in a Dynamic Rapid Serial Visual Presentation (RSVP) Task

by Anthony J. Ries and Gabriella Brick Larkin

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14. ABSTRACT

The current study evaluated the relationship between reaction time performance and the visual target-evoked P3 event-related potential (ERP) using a dynamic rapid serial visual presentation (RSVP) task. Electroencephalography (EEG) and reaction time measures were obtained while observers monitored an RSVP stream of short videos for infrequent targets presented among frequent nontarget distractors. Observers' reaction time quartiles were used as ERP binning parameters for target- and response-locked EEG epochs. This procedure allowed us to assess neural activity related to perceptual and response processing across different levels of overt performance. P3 amplitude and latency were evaluated for both stimulus and response-locked averages. The results showed that the peak latency of the stimulus-locked P3 was maximal over central parietal electrode Pz and was significantly different between each quartile; however, these latency differences were absent when P3 latency was measured in the response-locked data. The P3 amplitude analysis revealed no significant differences between stimulus and response-locked averages within each quartile. Overall, the results suggest the peak latency of the P3 obtained in the current study reflects processes more associated with motor planning and response execution.

15. SUBJECT TERMS

P300, RSVP, EEG, target recognition, reaction time, ERP

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1. Introduction/Objective

The P300 or P3 event-related potential (ERP) is a prominent neural signature used to index higher-order cognitive processing as a diagnostic tool in clinical applications and as an input signal in many brain computer interactive technologies (BCITs) for both patients and healthy individuals. ERPs are extracted from the electroencephalograph (EEG) signal by time-locking to a relevant stimulus and averaging over multiple trials (Luck, 2005). Generally, both the amplitude and latency of the waveform are measured (Polich, 2012). The P3 is usually evaluated using a two-stimulus oddball task where an infrequent "oddball" target stimulus (e.g., green circle, 1000-Hz tone) is presented among a series of many frequent nontarget distractor stimuli (e.g., blue squares; 500-Hz tones) where only the infrequent target stimulus requires a response by the observer (Polich, 2007). In these standard laboratory-based oddball experiments, the time between stimulus presentations typically ranges between 1 and 3 s, and the probability of an oddball appearing is generally between 0.1 and 0.2. Task-relevant visual stimuli presented in an oddball paradigm generate a P3 with a parietal scalp distribution. In contrast, an infrequent novel stimulus not requiring a response (in the case of a three-stimulus oddball task) evokes a P3 that is maximal over frontal and central electrode locations. These subcomponents of the P3 are often referred to as the P3b and P3a, respectively (Dien et al., 2004; Polich, 2007). In each case, P3 amplitudes are significantly larger than nontarget distractors.

A longstanding position regarding the functional role of the P3 is supported by the context updating theory, which states that each presented stimulus is evaluated with respect to the current context it is presented in. Under this view, the P3-related process is engaged when information from a task-irrelevant or task-relevant low-probability stimulus is different from the current mental representation induced by the current context of high-probability irrelevant stimuli (Donchin, 1981; Donchin and Coles, 1988). Seeing a stimulus that is different from what has recently been presented requires a revision of the current mental model to account for the unexpected or task-relevant information. Under this view, P3 latency is a useful metric for stimulus processing time since it covaries with the perceptual analysis of a stimulus and not factors affecting response selection (Dien et al., 2004; Magliero et al., 1984).

However, recent data have challenged the strict contextual updating hypothesis of the P3, suggesting that the target-generated P3 component is indicative of a process that mediates *both* perceptual analysis *and* response initiation. This account posits a mechanism that equally monitors the stimulus classification as well as the appropriate action required by it (Verleger et al., 2005). Verleger et al. (2005) suggest that the target-generated P3 may reflect a monitoring process that begins in parallel to the decision about the incoming stimulus. Specifically, it may reflect a "process that is evoked by a first classification of the stimulus and that reaches its peak when the consequence of this classification is being launched" (Verleger et al., 2005, p. 15). The

P3 obtained in simple discrimination tasks requiring speeded responses may indicate the end of stimulus evaluation and the onset of the decision to respond, which is in line with previous accounts of P3 function (McDowell et al., 2002; Squires et al., 1973; Verleger et al., 2005); however, little work has been done to systematically investigate the functional role of the P3 as it relates to reaction time performance using more ecologically valid stimuli than those used in basic laboratory tasks. Assessing the role of the P3 using stimuli with high external validity has the potential to benefit real-world BCI systems.

The current study expanded on previous P3 research by executing a task using realistic, dynamic stimuli in the form of short videos, and combining the fast presentation rate found in rapid serial visual presentation (RSVP) with the low probability of target occurrence commonly seen in standard oddball tasks. We implemented an RSVP paradigm using short video sequences to see if the standard P3 findings obtained with simplistic stimuli commonly used in an oddball paradigm generalize to more dynamic situations. Additionally, we investigated the relationship between reaction time performance and characteristics of the P3. Similar to Verleger et al. (2005), we tested the hypothesis that the target-related P3 is reflective of the integration of stimulus perception and response. If the P3 reflects processes related to stimulus evaluation independent of response in the present task, then stimulus-locked averages should be larger than response-locked averages. However, if the P3 equally reflects both perceptual processing and response initiation, then quartile averages should have similar amplitudes in stimulus and response-locked averages, and P3 latencies should vary across quartiles in both stimulus and response-locked data. To test these hypotheses, we analyzed the neural activity evoked from targets as a function of reaction time by binning target epochs into response time quartiles (for a review on RT binning for ERPs, see Poli et al. [2010]). If the P3 from the target-relevant stimuli is equally related to both stimulus and response operations, then P3 latency should vary as a function of response time quartile in both stimulus and response-locked averages. In the same vein, P3 amplitude will be equally large in both stimulus and response-locked averages if P3b is equally related to the stimulus and response.

2. Methods

2.1 Participants

Fifteen participants (nine male, average age 39.5) volunteered for the current study. Participants provided written informed consent, reported normal or corrected-to-normal vision, and reported no history of neurological problems. Fourteen of the fifteen participants were right-handed.

The voluntary, fully informed consent of the persons used in this research was obtained as required by 32 CFR 219 (1999) and AR 70-25 (1990). The investigator has adhered to the policies for the protection of human subjects as prescribed in AR 70-25 (1990).

2.2 Stimuli and Procedure

Cognitive Technology Threat Warning System (CT2WS) video clips were used in an RSVP paradigm (Touryan et al., 2010) (figure 1). Observers were instructed to make a manual button press with their dominant hand when they detected a target (person or vehicle). Video clips consisted of five consecutive images, each 100 ms in duration; each video clip was presented for 500 ms. There was no interval between videos such that the first frame was presented immediately after the last frame of the prior video. If a target appeared in the video clip, it was present on each 100-ms image. The distractor-to-target ratio was 90/10. RSVP sequences were presented in 2-min blocks after which time observers were given a short break. Observers completed 25 blocks.

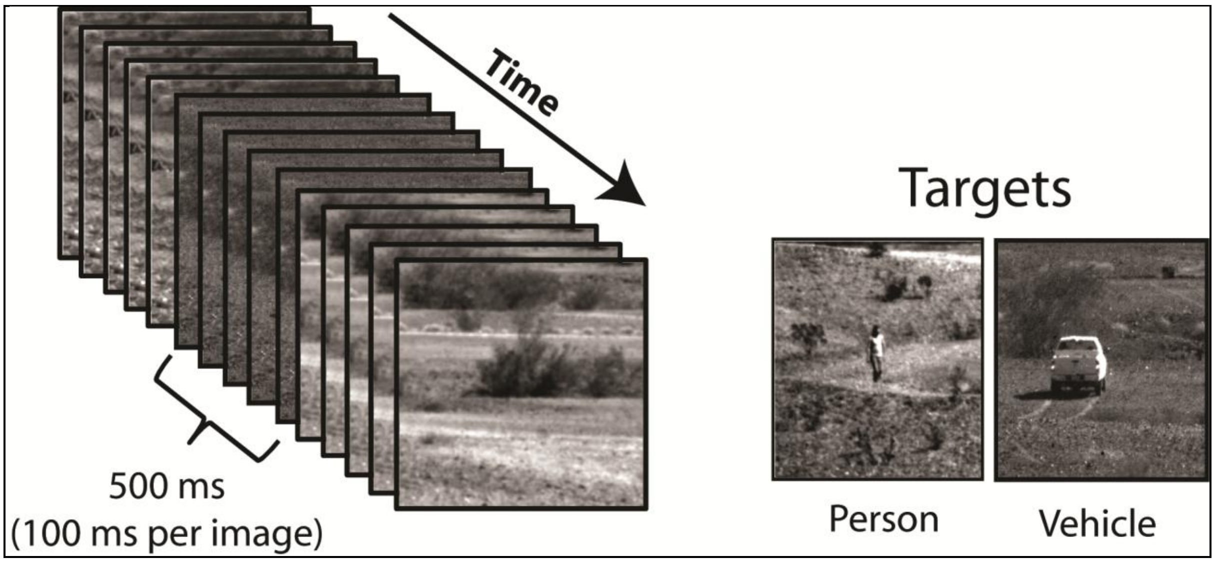

Figure 1. Sequence of short videos presented in RSVP.

2.3 EEG Recording and Analysis

Electrophysiological recordings were digitally sampled at 512 Hz from 64 scalp electrodes arranged in a 10–10 montage using a BioSemi Active Two system (Amsterdam, Netherlands). External leads were placed on the outer canthus and below the orbital fossa of both eyes to record electrooculography (EOG). Continuous EEG data were referenced offline to the average of the left and right earlobes and digitally filtered 0.1–55 Hz. EOG and electromyography artifacts were removed using independent component analysis (Jung et al., 2000).

EEG data were processed and analyzed using EEGlab and ERPlab (Delorme and Makeig, 2004; Luck and Lopez-Calderon, 2010). Continuous artifact-free data were epoched –1500 to 1500 ms around target and response onset. Targets followed by a button press within 200 to 1000 ms were included in the analysis. Averaging across all trials in a given condition may mask meaningful brain dynamics associated with performance, especially in perceptually difficult tasks where the variance in ERP latency and reaction time (RT) increases (Luck, 2005).

Therefore, to assess the brain dynamics associated with varying levels of RT performance, target epochs were sorted into bins corresponding to an individual participant's reaction time quartile (Poli et al., 2010). Grand averages across all subjects were then created for each stimulus and response-locked quartile.

For each subject, P3 peak latency and amplitude were calculated for stimulus- and response-locked averages in each quartile. Peak latency was measured at electrode Pz as this was the electrode showing the largest P3 amplitude and is consistent with prior research investigating P3 waveforms related to target detection. Peak latency was designated as the time at which the waveform reached maximum positivity between 300 and 900 ms in stimulus-locked averages and –200 to 400 ms in response-locked averages. Latency values for each quartile in stimulus and response-locked measures were used as a centering parameter (±–50 ms) to measure P3 amplitude. That is, each subject's P3 amplitude was measured separately for stimulus and response-locked averages in each quartile by obtaining the average value from ±50 ms of the peak latency value. Importantly, the P3 amplitude for stimulus and response-locked data were referred to the same baseline (–200 to 0 ms prestimulus onset). This ensured the amplitudes between these two conditions could be meaningfully compared.

3. Results

3.1 Behavior

Target accuracy across all subjects ranged between 89% and 97%. Reaction times were obtained from correct target trials and showed a median RT of 541.14 ms with an interquartile range of 472.66 to 591.78 ms. Figure 2 shows an RT distribution from a single subject. For each subject, reaction time quartiles were used as binning parameters for the ERP analysis.

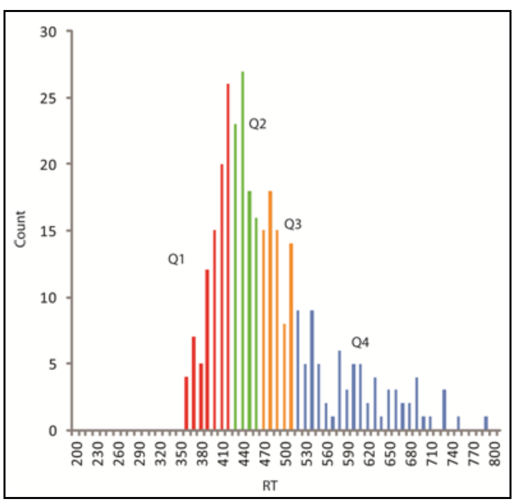

Figure 2. Distribution of target reaction times from subject S18.

3.2 Stimulus-Locked ERPs

Stimulus-locked P3 latency and amplitude data were submitted to a one-way ANOVA with the main factor of quartile containing four levels. Stimulus-locked P3 latency analysis showed a significant main effect of quartile, $F(3,42) = 69.37$, $p < 0.001$. Subsequent *t*-tests revealed each quartile was significantly different ($\alpha = 0.05$) from each other after correction for multiple comparisons using Tukey's method (figure 3) indicating that P3 latency increased as RT became slower. A main effect for quartile was also obtained for P3 amplitude, $F(3, 42) = 4.48$, $p = 0.008$; however, the only significant difference was between quartile 2 and quartile 4 ($\alpha = 0.05$) after correcting for multiple comparisons using Tukey's method showing quartile 2 had a significantly larger amplitude than quartile 4. The ERP image plot in figure 4 shows the single trial relationship between the stimulus-locked P3 brain dynamics and RT. Tables 1 and 2 show the pairwise comparisons between each quartile for the latency and amplitude analysis, respectively.

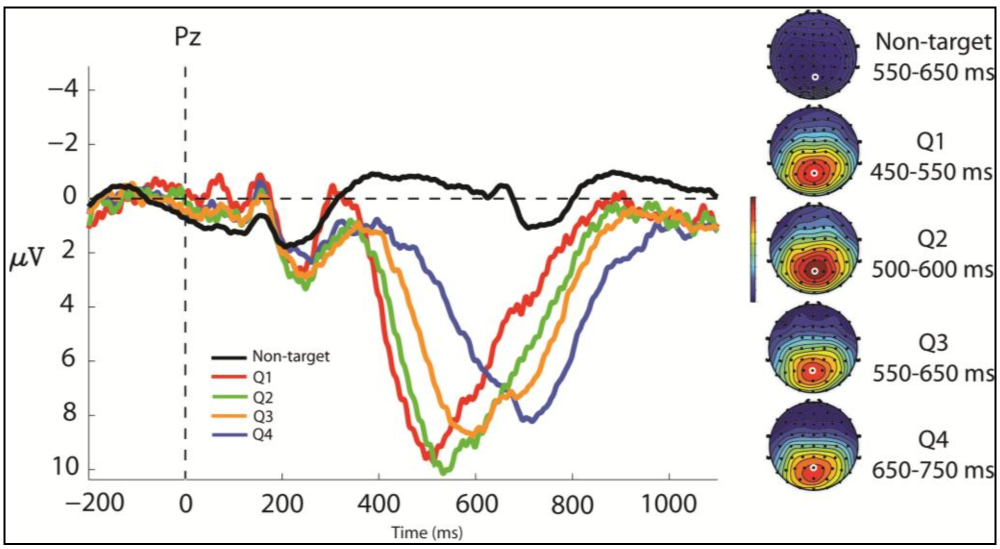

Figure 3. Left: stimulus-locked P3 event-related potentials at electrode Pz from nontargets and targets in each quartile. Right: corresponding scalp topographical voltage maps with electrode Pz highlighted and plotted ±–50 ms surrounding the peak of the P3 (targets only).

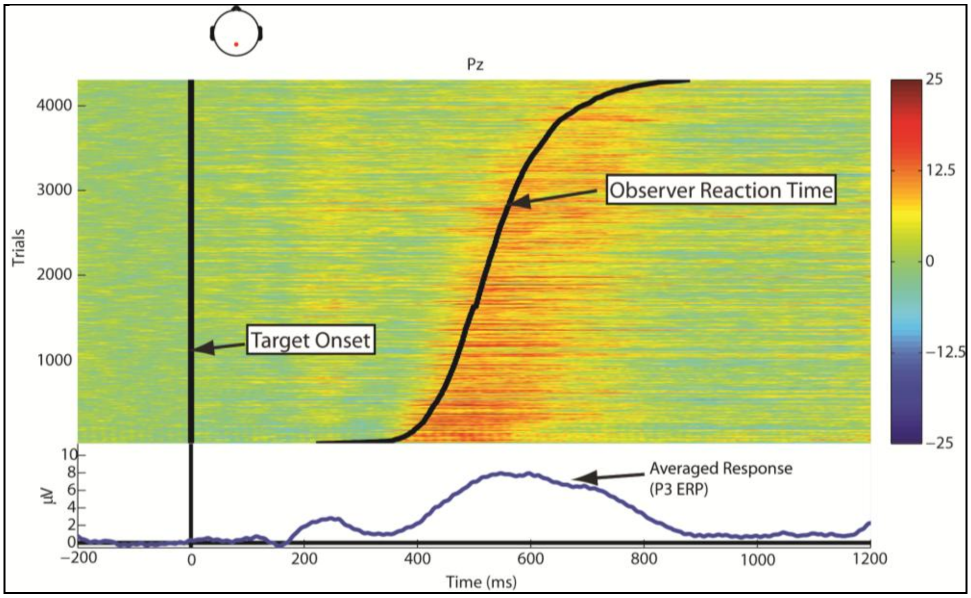

Figure 4. Stimulus-locked ERP image plot sorted by response time showing the relationship between P3 brain dynamics and performance (smoothed with a 10-trial moving average).

Table 1. Paired t-test statistics for stimulus-locked P3 latency. The critical t statistic using Tukey's method is ±–2.91.

Target Quartiles	Stimulus-Locked P3 Latency Paired Differences					t	df	Sig. (two-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Q1-Q2	–32.29	17.09	4.41	–41.75	–22.83	–7.32	14	0.000
Q1-Q3	–85.42	52.62	13.59	–114.56	–56.28	–6.29	14	0.000
Q1-Q4	–173.18	52.30	13.50	–202.14	–144.22	–12.83	14	0.000
Q2-Q3	-53.12	54.96	14.19	–83.56	–22.69	–3.74	14	0.002
Q2-Q4	–140.89	48.61	12.55	–167.81	–113.96	–11.22	14	0.000
Q3-Q4	–87.76	60.62	15.65	–121.33	–54.19	–5.61	14	0.000

Table 2. Paired t-test statistics for stimulus-locked P3 amplitude. The critical t statistic using Tukey's method is ±–2.91.

Target Quartiles	Stimulus-Locked P3 Amplitude Paired Differences					t	df	Sig. (two-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Q1-Q2	–0.66	1.00	0.26	–1.21	–0.10	–2.54	14	0.024
Q1-Q3	0.13	1.92	0.50	–0.94	1.19	0.26	14	0.802
Q1-Q4	1.67	2.80	0.72	0.13	3.22	2.32	14	0.036
Q2-Q3	0.78	2.23	0.58	–0.45	2.02	1.36	14	0.196
Q2-Q4	2.33	2.90	0.75	0.72	3.94	3.11	14	0.008
Q3-Q4	1.55	2.36	0.61	0.24	2.85	2.54	14	0.024

3.3 Response-Locked ERPs

Response-locked P3 latency and amplitude data were submitted to a one-way ANOVA using the same factors as in the previous analysis. Response-locked P3 latency showed no main effect of quartile, $F(3,42) = 0.26$, $p = .853$, suggesting no systematic differences between P3 latency and RT quartile (figure 5 and table 3). While a main effect for quartile was obtained for P3 amplitude, $F(3, 42) = 4.24$, $p = .01$, no significant differences remained after correcting for multiple comparisons using Tukey's method (table 4). Figure 6 shows the relationship between the response-locked P3 brain dynamics and RT.

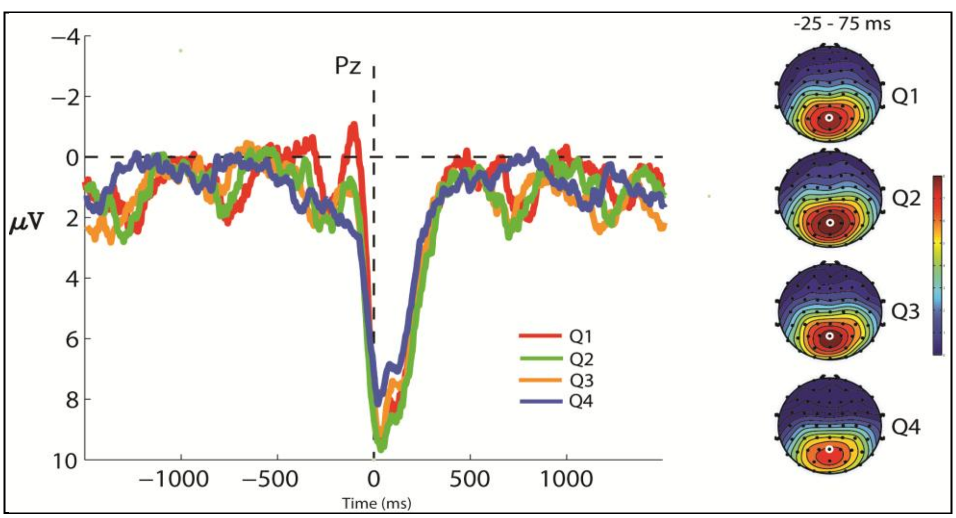

Figure 5. Left: response-locked P3 event-related potentials at electrode Pz from targets in each quartile. Right: corresponding scalp topographical voltage maps with electrode Pz highlighted.

Table 3. Paired t-test statistics for response-locked P3 latency. The critical t statistic using Tukey's method is ±–2.91.

Target Quartiles	Response-Locked P3 Latency Paired Differences					t	df	Sig. (two-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Q1-Q2	7.94	20.09	5.19	–3.18	19.07	1.53	14	0.148
Q1-Q3	6.77	56.44	14.57	–24.48	38.02	0.46	14	0.649
Q1-Q4	9.37	38.00	9.81	–11.67	30.42	0.96	14	0.356
Q2-Q3	–1.17	58.64	15.14	–33.65	31.30	–0.08	14	0.939
Q2-Q4	1.43	38.02	9.82	–19.62	22.49	0.15	14	0.886
Q3-Q4	2.60	44.72	11.55	–22.16	27.37	0.23	14	0.825

Table 4. Paired t-test statistics for response-locked P3 amplitude. The critical t statistic using Tukey's method is ±–2.91.

Target Quartiles	Response-Locked P3 Amplitude Paired Differences					t	df	Sig. (two-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Q1-Q2	0.05	1.00	0.26	–0.50	0.61	0.21	14	0.835
Q1-Q3	0.63	1.24	0.32	–0.05	1.32	1.99	14	0.067
Q1-Q4	1.83	2.59	0.67	0.40	3.27	2.74	14	0.016
Q2-Q3	0.58	1.94	0.50	–0.50	1.65	1.15	14	0.268
Q2-Q4	1.78	2.83	0.73	0.21	3.34	2.44	14	0.029
Q3-Q4	1.20	2.42	0.62	–0.14	2.54	1.92	14	0.075

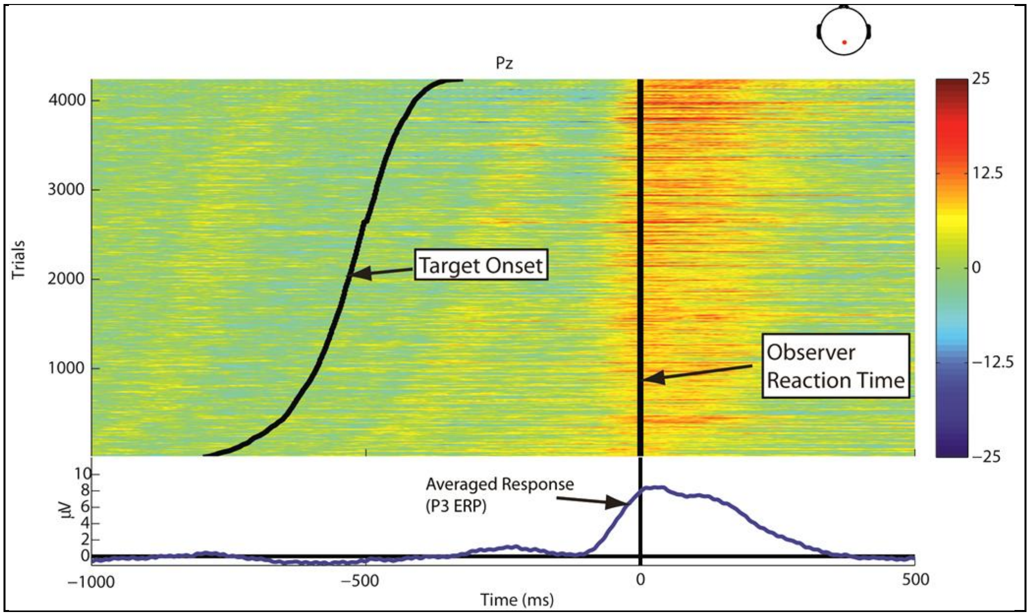

Figure 6. Response-locked ERP image plot sorted by target onset showing the relationship between P3 brain dynamics and performance (smoothed with a 10-trial moving average).

3.4 Stimulus and Response-Locked ERP Amplitude Comparison

P3 amplitude values were submitted to a 2 × 4 repeated measures ANOVA with the factors reference event (stimulus- or response-locked) and quartile (1, 2, 3, or 4). P3 latency increased with quartile in stimulus-locked data but did not change in the response-locked data as revealed by the reference event by Quartile interaction, $F(3,42 = 112.11$, $p < 0.001$; quartile in stimulus-locked data: $F(3,42 = 69.37$, $p < 0.001$; quartile in response-locked data: $F(3,42 = 0.26$, $p = 0.853$).

The results revealed no main effect for reference event $F(1,14) = 0.132$, $p = 0.722$, suggesting no significant difference between stimulus- and response-locked amplitude. There was no reference event by quartile interaction $F(3,42) = 0.596$, $p = 0.621$, suggesting amplitude measures were similar within quartiles between stimulus and response-locked averages (figure 7).

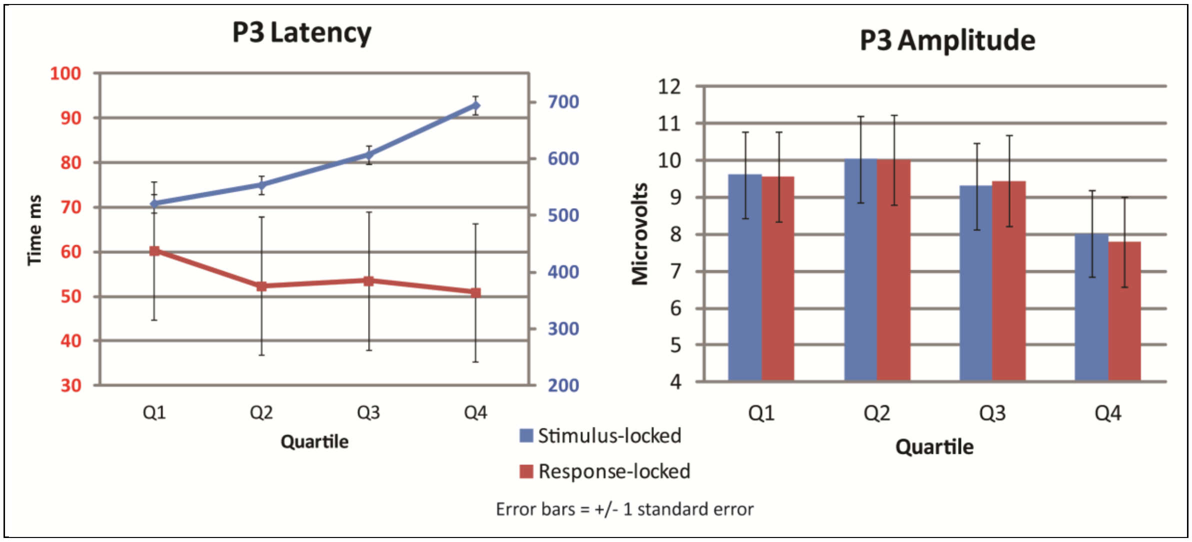

Figure 7. P3 latency (left) and amplitude (right) in each target quartile for both stimulus- and response-locked data.

4. Discussion/Conclusion

The current study employed a dynamic RSVP task using short-duration videos to evaluate the relationship between reaction time performance and the visual target-evoked P3ERP. The results suggest the P3 obtained in the current study reflected processes associated with motor planning and response execution. The peak latency of the stimulus-locked P3 over electrode Pz was significantly different between each quartile. However, unlike the findings by Verleger et al. (2005), these differences were absent when P3 latency was measured in the response-locked data as the P3 peaked at nearly the same latency for each quartile when averages were locked to the response. This finding is consistent with other RSVP research, showing high association between reaction time and the peak of the late positive complex over midline parietal electrodes (Gerson et al., 2005). Others, using a non-RSVP visual selective attention task, have also found that target-evoked P3 components were time-locked to the motor responses (Jung et al., 2000). Together this suggests a strong link between the P3 and processes related to motor planning and execution.

However, one important difference between the present study and prior research is the relatively uncontrolled properties of the stimulus. In most P3 studies, all of the oddball or target stimuli are identical and thus equally visible (e.g., Polich [2007]). This removes any potential variability due to early perceptual processing, such as figure-ground segmentation and object recognition. Some previous studies have used a range of target stimuli (e.g., different people or animals within a natural scene) (Gerson et al., 2005). However, even in these RSVP paradigms, all targets are approximately equally visible, occupying roughly the same number of pixels per image. In the CT2WS stimulus set, target size and level of occlusion varies substantially. Thus, some of the variability in the stimulus-lock latency could be due to the low-level perceptual difference in target visibility. Further analysis of the stimulus properties may reveal a significant link between the stimulus features and P3 latency.

Additionally, this study assessed whether standard P3 findings obtained with simplistic stimuli commonly used in an oddball paradigm generalize to more dynamic operational situations. The P3 waveform obtained in the current study was found for only targets and not nontarget distractors and had a scalp distribution maximal over central parietal electrodes, specifically, Pz. The results showed that low-probability targets (presented via RSVP of short video sequences) produced the standard target P3 observed in many laboratory tasks using less complex stimuli and slower rates of presentation.

The results suggest a response-related association with the P3 function in the current task; however, studies have shown that targets can also trigger a P3 when no overt response is required (e.g., Heinrich et al., 2009). These findings suggest that the P3 may reflect the end-of-stimulus evaluation, but that an overt motor response requirement is not necessary for its generation. This idea may be explained by considering the parallel visual pathways that lead to action and object perception. Tasks requiring an overt response would engage more dorsal stream processes, while target perception and identification would be primarily processed in the ventral stream (Milner and Goodale, 1995). It is possible that during a visual target detection task, such as the one presented in the current experiment, the parallel operations of the dorsal and ventral visual processing streams contribute to the P3 response, but dorsal stream activation is not required for its generation.

While the latency findings do indicate a strong link between the P3 and stimulus response, processes associated with stimulus evaluation cannot be ruled out. The task in the present experiment only required a simple go/no-go response that could be easily determined by the stimulus information. Many of the targets were easy to detect because of their motion thereby making them salient. P3 latencies are highly correlated with RTs in tasks that require fast responses (Verleger, 1997). Because of the simple response requirement and high accuracy rates, there was likely little variability between the time a stimulus was identified as a target and the response initiation. Therefore, the peak latency of the P3 obtained in the current study may reflect the end of the stimulus evaluation process and the execution of the planned motor response consistent with the theory by Verleger et al. (2005).

Further support of an integrative role of the P3 in linking perception to reaction is found in the amplitude analysis. P3 amplitudes were similar in each quartile and did not differ between stimulus and response-locked averages, nor did they all significantly differ between quartiles. If the peak amplitude of the P3 only reflected processes related to stimulus evaluation, then the P3 amplitude should be reduced in response-locked data with respect to stimulus-locked data, since the stimulus-related process would peak at varying times relative to the response onset. The amplitudes being similar in stimulus- and response-locked averages suggest that stimulus evaluation and response-related processes equally contribute to the P3, especially when using more ecologically valid stimuli. Future studies using dynamic RSVP should incorporate low-probability nontarget stimuli that do not require a response to further examine the role of the P3 as it relates to stimulus evaluation and response execution.

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List of Symbols, Abbreviations, and Acronyms

BCIT	brain computer interactive technology
CT2WS	Cognitive Technology Threat Warning System
EEG	electroencephalogram
EOG	electrooculography
ERP	event-related potential
P3	P300
RSVP	rapid serial visual presentation
RT	reaction time

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